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AN OCCURRENCE OF SPADAITE AT GOLD HILL, UTAH¹

W. T. SCHALLER AND T. B. NOLAN,
United States Geological Survey.

INTRODUCTION

During the survey of the Gold Hill quadrangle in west central Utah, several specimens of an unusual type of gold ore were collected by one of us (T. B. N.). On microscopic examination these specimens were found to contain considerable quantities of a fine-grained shreddy mineral which could be referred only to the very rare mineral spadaite on the basis of optical and chemical tests (by W. T. S.). This mineral was described² by von Kobell in 1843, as occurring with wollastonite at Capo di Bove, near Rome, Italy. The only other recorded occurrence of spadaite is that given³ by Fischer who identified it by its qualitative chemical composition in amygdular dolerite at Sasbach, Kaiserstuhl, Germany. He differentiated it from steatite by its blowpipe fusion to a white enamel, with bubbling, and by its decomposition by HCl acid with separation of sandy silica.

The occurrence in Utah, here described, is therefore the third recorded identification of spadaite. The mineral may be more widespread in its occurrence than is recognized and may have been erroneously determined as serpentine.

OCCURRENCE AND ASSOCIATION

The geology of the region has been briefly described by Butler⁴ and by Kemp and Billingsley⁵ and will be treated in more detail in

¹ Published by permission of the Director, U. S. Geological Survey.

² See Dana, *System of Mineralogy*, 6th ed., p. 682.

³ Fischer, C., *Neues Jahrb. f. Min., Geol. u. Pal.*, 1865, p. 442.

⁴ Butler, B. S., *Ore deposits of Utah: U. S. Geol. Survey, Prof. Paper 111*, pp. 469-482, 1920.

⁵ Kemp, J. F., and Billingsley, P., *Geology of Clifton mining district and vicinity, Tooele County, Utah: Econ. Geol.*, vol. 13, pp. 247-274, 1918.

a Geological Survey publication by one of the writers.⁶ A considerable thickness of complexly faulted and folded Paleozoic sedimentary rocks was intruded in early Tertiary time by a stock of quartz monzonite. Several kinds of ore deposits were formed as an after effect of the intrusion. In one of these—gold-bearing lodes in rather thoroughly silicated limestone—spadaite occurs locally in considerable quantity.

This type of gold ore was mined at the Cane Springs, Alvarado, and Midas mines, all of which are now idle. At all three, the geology is more or less similar. One or more beds of limestone have been rather completely converted to a rock composed of wollastonite, garnet, diopside, and other silicates. Shoots of gold ore are localized in these beds by pre-ore faults at the Midas and Cane Springs mines, and by an irregular dike-like mass of quartz monzonite at the Alvarado mine.

Spadaite occurs only in the ore shoots, associated with the silicates mentioned, quartz, various sulphides (chiefly chalcopyrite and bornite) and their oxidation products, and small quantities of native gold. The spadaite forms dense, almost porcellanous, cream or pink colored masses in the ore shoots. These dense masses of spadaite generally contain blebs of garnet, diopside, and other silicates. Irregular areas and veinlets of quartz with associated metallic minerals also traverse the spadaite.

Thin sections of specimens containing spadaite show clearly that it is later than the silicate minerals which have been formed by the metamorphism of the limestone bed, a conclusion that is also indicated by the absence of spadaite in altered limestone away from the ore shoots. Wollastonite is the most common of the older silicate minerals and it appears to be preferentially replaced by the spadaite, for blebs of garnet and of diopside of about the same size and habit as blebs of the same minerals in unreplaced wollastonite are found in the spadaite. The incomplete replacement of wollastonite by spadaite is shown in Fig. 1. The shreddy spadaite incloses many irregularly shaped residua of wollastonite. The spadaite is clearly older than the quartz, in many places being veined by it. Locally also calcite veinlets are found in the spadaite masses.

⁶ Nolan, T. B., Geology and ore deposits of the Gold Hill quadrangle, Utah: *U.S. Geol. Survey report*, in preparation.

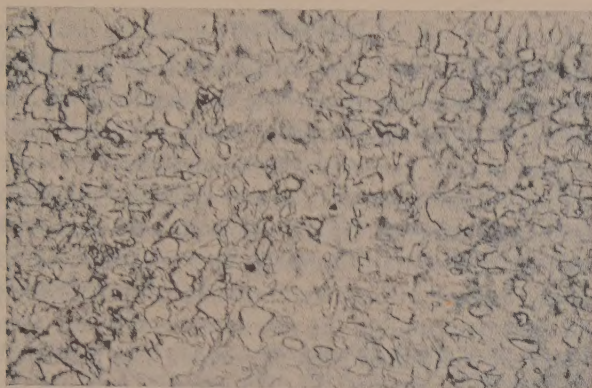


FIG. 1. Microphotograph of spadaite inclosing residua of wollastonite. Plain light, $\times 87$.

PROPERTIES

Under the microscope the spadaite is seen to have a felted shreddy habit, like that of sericite, from which it differs, however, in its much lower indices of refraction and lower birefringence. It is indistinctly platy, somewhat columnar, rather than fine fibrous. The mineral is colorless and non-pleochroic. The extinction is nearly parallel, though some fragments show a distinct but slightly inclined extinction. The refractive indices were determined by Dr. C. S. Ross to be: $\alpha=1.521$, $\beta=1.525$, $\gamma=1.545$; all ± 0.003 . 2V small to medium. Optically positive, elongation positive. Larsen gives⁷ $\beta=1.53 \pm 0.01$ for spadaite from Italy.

The refractive indices, after heating to 110° and driving off half the water, are nearly the same but seem to be very slightly (not more than 0.01) higher. Apparently some minerals can lose half their water without appreciable change in their optical properties. Thus Winchell⁸ states for talc:

"After losing half its water content the mineral has practically the same optic properties."

The density of the specimen analyzed is 2.32. Allowing for the insoluble garnet and diopside and for the soluble wollastonite, the density of spadaite is about 2.2.

⁷ Larsen, E. S., *U. S. Geol. Survey, Bull. No. 679*, p. 135, 1921.

⁸ Winchell, A. N. *Elements of optical mineralogy*, Part II: Descriptions of minerals, 1927, p. 228.

COMPOSITION

The mineral fuses before the blowpipe flame, with slight bubbling, to an opaque white enamel. It is soluble in HCl without gelatinization, yielding sandy silica. Neither dilute nor concentrated acid, hot or cold, caused any gelatinization.

A preliminary separation with heavy solution yielded about 4 per cent of heavy minerals (chiefly diopside and garnet), but the sample analyzed still contained nearly 9 per cent of these minerals, so that about 13 per cent of minerals insoluble in HCl are present in the hand specimen. Boiling the powdered sample for 15 minutes with a 10 per cent solution of Na_2CO_3 yielded 0.41 per cent of soluble silica, which is ascribed to opal. The lime is referred to wollastonite. A mere trace of carbonate is also present.

The analysis of the mineral is given below in the first column and, in the second column, the analysis is recalculated after deducting the impurities (insoluble garnet and diopside, wollastonite and opal).

TABLE 1. ANALYSIS OF SPADAITE FROM UTAH

Analysis		With impurities deducted ^a	Ratios		Calculated for $\text{SiO}_2 \cdot$ $\text{MgO} \cdot 2\text{H}_2\text{O}$
Insol. residue	8.68	—			—
SiO_2 sol. in Na_2CO_3	0.41	—			—
SiO_2	43.28	47.57	.7915	1.13 or 1	44.06
Fe_2O_3	0.22	—			—
FeO	0.27	0.31	.0043	1.00 or 1	—
CaO	1.58	—			—
MgO	24.72	28.28	.7017		29.54
H_2O —	10.36	11.85	.6583	0.93 or 1	13.20
H_2O +—	10.51	12.02	.6678	0.94 or 1	13.20
	100.03	100.03			100.00

^a The impurities consist of 8.68 per cent insoluble residue (diopside and garnet), 3.27 per cent wollastonite (based on the CaO percentage), 0.41 per cent opaline silica (soluble in 10 per cent Na_2CO_3 solution), and 0.22 Fe_2O_3 as limonite.

The ratios came out approximately to 1:1:2, yielding the formula $\text{SiO}_2 \cdot \text{MgO} \cdot 2\text{H}_2\text{O}$, which may be written $\text{H}_2\text{MgSiO}_4 \cdot \text{H}_2\text{O}$, half of the total water being given off at 110° .

The question as to how the water given off at 110° functions is one that cannot be answered for this mineral at present. The fact

that the optical properties do not seem to vary to any great extent, when this water at 110° is driven off, cannot be given too much weight as the character of the material is such that the optical properties cannot be determined sufficiently accurately and fully to make such a criterion of much value.

Assuming that this water at 110° is unessential to the mineral and deducting it, and recalculating the remainder to the same total (100.03), the resultant analysis agrees fairly closely with the only recorded analysis of spadaite.

TABLE 2. COMPARISON OF ANALYSIS OF SPADAITE FROM UTAH, WITH THE WATER GIVEN OFF AT 110° DEDUCTED, WITH THE ANALYSIS OF SPADAITE FROM ITALY, AND WITH THE CALCULATED COMPOSITION FOR $\text{SiO}_2 \cdot \text{MgO} \cdot \text{H}_2\text{O}$.

	Spadaite from Utah with H_2O at 110° deducted	Spadaite from Italy	Calculated for $\text{SiO}_2 \cdot \text{MgO} \cdot \text{H}_2\text{O}$
SiO_2	53.96	56.00	50.76
FeO	0.35	0.66	—
MgO	32.08	30.67	34.04
H_2O	13.64	11.34	15.20
Al_2O_3	—	0.66	—
	100.03	99.33	100.00

The ratios of $\text{SiO}_2:\text{MgO}:\text{H}_2\text{O}$ in the analysis of spadaite from Italy (Table 2) are 1.21:1.00:0.82, with a considerable variance from the 1:1:1 ratio. The ratios are close to the formula given, namely, $6\text{SiO}_2 \cdot 5\text{MgO} \cdot 4\text{H}_2\text{O}$; being 5.99:4.95:4.05. The ratios of the analysis of spadaite from Utah (Table 2), with H_2O at 110° deducted, are 5.48:4.89:4.63, a poor agreement.

In von Kobell's paper describing spadaite from Italy he makes no mention of drying the sample at 100° before analysis, but this practice was so common at that time that it can probably be safely assumed that his sample was so dried and that consequently the spadaite from Italy contained more water than is reported in the analysis. The 0.66 per cent Al_2O_3 reported has to be considered and it may be that by making the proper allowance for the Al_2O_3 and for the water lost, if his sample was dried at 100° , the ratios would come closer to a 1:1:2 ratio than those calculated from his recorded analysis.

It is, therefore, believed that the same mineral is represented by

the two occurrences and that the correct formula of spadaite is $\text{SiO}_2 \cdot \text{MgO} \cdot 2\text{H}_2\text{O}$ (as shown in Table 1) even though both analyses show an excess of silica and the quantity of water inherently present in the mineral is not definitely known.

A number of mineral names are listed in fine print on page 675 of Dana's *System of Mineralogy* whose analyses approach the simple formula $\text{SiO}_2 \cdot \text{MgO} \cdot \text{H}_2\text{O}$, such as hampshirite, aphrodite, and cerolite (or kerolite). But as described by Schrauf,⁹ most of these are mixtures of serpentine and opal, unless Schrauf also confused spadaite with serpentine. Some analyses of cerolite are close to the analysis of spadaite from Utah (Table 1) and may represent the same mineral. The recorded analyses of deweylite are similarly close.

Our knowledge of the hydrous magnesium silicates is still very incomplete. The following tabulation suggests a possible grouping:

THE HYDROUS MAGNESIUM SILICATES

$\frac{\text{SiO}_2}{\text{MgO}} = < 1.$	Serpentine (incl. chrysotile and antigorite) Deweylite	$2\text{SiO}_2 \cdot 3\text{MgO} \cdot 2\text{H}_2\text{O}.$ $3\text{SiO}_2 \cdot 4\text{MgO} \cdot 6\text{H}_2\text{O}.$
$\frac{\text{SiO}_2}{\text{MgO}} = 1.$	Spadaite Cerolite Sepiolite Parasepiolite	$1\text{SiO}_2 \cdot 1\text{MgO} \cdot 2\text{H}_2\text{O}.$ Simple formula here proposed. $2\text{SiO}_2 \cdot 2\text{MgO} \cdot 3\text{H}_2\text{O}(?)$ or same as spadaite (?) $3\text{SiO}_2 \cdot 2\text{MgO} \cdot 2\text{H}_2\text{O}$ β -sepiolite $3\text{SiO}_2 \cdot 2\text{MgO} \cdot 4\text{H}_2\text{O}$ α -sepiolite
$\frac{\text{SiO}_2}{\text{MgO}} = > 1.$	Talc or Spadaite	$4\text{SiO}_2 \cdot 3\text{MgO} \cdot 1\text{H}_2\text{O}$ $5\text{SiO}_2 \cdot 4\text{MgO} \cdot 2\text{H}_2\text{O}(?)$ (Winchell). $6\text{SiO}_2 \cdot 5\text{MgO} \cdot 4\text{H}_2\text{O}(?)$ Old formula.

⁹ Schrauf, A., Beiträge zur Kenntniss des Associationskreises der Magnesia-silicate: *Zeit. f. Kryst., Min.*, vol. 6, pp. 321-388, 1882.

THE INFLUENCE OF THE ELECTRIC POLARIZABILITY ON THE GLIDING STRENGTH OF CRYSTALS

HANS MÜLLER, *Dept. of Physics, Mass. Institute of Technology.*

In a recent paper M. J. Buerger¹ discovered an interesting relation between the electric polarizability of the ions of face centered cubic crystals and their mode and ease of translation-gliding. Buerger's results of his investigation of the translation-gliding on 12 different isometric crystals of the NaCl type can be summarized as follows:

(a) If the sum of the polarizabilities of the two kinds of ions is small, the crystal has a high gliding strength, and glides only along the (110) plane. (Examples NaCl, NaF, MgO).

(b) The larger the sum of the polarizabilities, the smaller the gliding strength (the greater the plasticity) and the smaller the gliding strength for gliding in the (001) plane, relative to the strength for gliding in the (011) plane. Crystals with ions of large polarizability (PbTe, PbS, KI) have a small gliding strength and glide only along the (001) plane, while crystals with ions of medium polarizability (NaI, KBr, NaBr, KCl) have a medium gliding strength and glide along both planes.

(c) The gliding in either plane takes place in the direction $[\bar{1}10]$, which is the direction of shortest distance between two ions of the same kind. Fig. 1 illustrates the two possible modes of gliding in a crystal of the type NaCl.

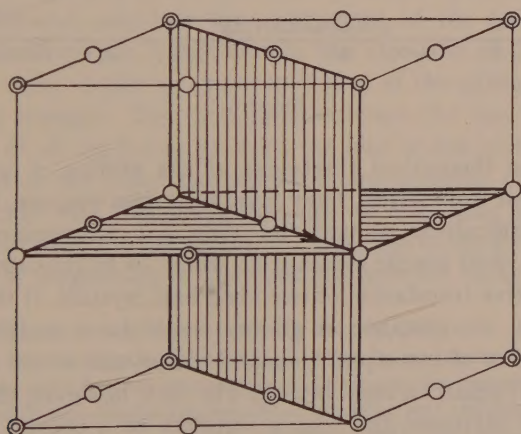


FIG. 1.

¹ M. J. Buerger, *Am. Mineralogist*, Vol. 15, Nos. 2, 5, 6 (1930).

These results lead to the following relations between the gliding strengths in the two respective planes and the sum of the polarizabilities:

(1) If the ions are not polarizable, the gliding strength for the (001) plane is much larger than this for the (011) plane.

(2) Both gliding strengths decrease with increasing polarizability, but the decrease must be faster for the (001) plane.

Fig. 2 illustrates the type of relationship which must exist between gliding strength and polarizability according to Buerger's measurements.

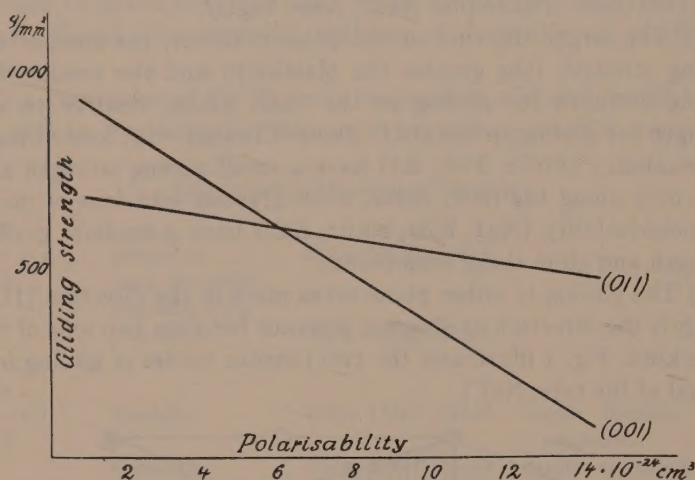


FIG. 2.

A rigorous theoretical treatment of the gliding of crystals encounters great difficulties. They arise from two sources. First, it is extremely difficult to picture the molecular arrangement during gliding. The most simple assumption would be to consider the gliding as a relative translation of two ideal half crystals. If this picture were correct, the distance of gliding would be a multiple of the closest distance of two equal ions, and the crystal would after gliding represent again an ideal lattice. The fact, however, that plastic deformation increases the tensile strength of a crystal indicates, and the X-ray diagrams show it directly, that after gliding the lattice arrangement is disturbed. The second difficulty arises from the limited knowledge of the forces acting between the ions of the crystal. These forces are generally considered to be the electro-

static forces between the ionic charges and certain repulsive forces which are due to the finite size of the ions. Unsöld has given an explanation of the origin of these repulsive forces with the help of wave mechanics. It is generally assumed that they are spherically symmetric and decrease with the inverse 9th or 11th power of the distance. Lennard-Jones² and his collaborators have investigated the values of n and A in a power law, $F = A/r^n$ for a large number of ions. It is however most probable that this approximation holds only if the ions are in the normal lattice distance. The approximation is sufficient to calculate elastic and equilibrium constants of the crystal, but is not sufficient to calculate the gliding strength, since during gliding the ions separate considerably. The value of the gliding strength depends very much on the choice of the repulsive forces, and since we have no definite information about them, it is entirely hopeless to calculate accurate values for the gliding strength.³ It is in particular impossible to explain the experimental fact, that the gliding strength along the (001) plane is larger than the one along the (011) plane, if the ions are not polarizable.

Frenkel⁴ attempted to calculate the gliding strength of NaCl, but his results are of no value (negative gliding strength for the 011 plane) since his assumptions about the repulsive forces are obviously too simple. Here we will only estimate the order of magnitude of the gliding strength, assuming the ions are not polarizable. For this purpose we consider the gliding as a relative translation of two halfcrystals, and calculate the component of the force between these two halfcrystals which acts in the direction of gliding. The maximum value of this force per unit area of the gliding-surface is the gliding strength. The total force between the two halfcrystals is the sum of all the forces between the ions of one halfcrystal and all the ions of the other halfcrystal. Since however all forces decrease quickly with increasing distance we only take into account the forces between the two layers on both sides of the gliding plane.⁵ The order of magnitude of the distance between these two layers

² Lennard-Jones, *Proc. of the Royal Society*, Vol. 109, (1925).

³ We have carried out calculations using Lennard Jones' data and also by replacing the inverse powerlaw by an exponential decrease of the repulsive forces. The results vary much with the assumption and do not agree with the observations. The calculations give in many cases a negative gliding strength. The few valuable conclusions resulting from these calculations are mentioned in this paper.

⁴ Frenkel, *Zeit. für Physik*, Vol. 37, 572 (1926).

⁵ A more accurate calculation shows that this approximation involves an error of less than 10%.

is the lattice distance a , hence the order of magnitude of the electric force between two ions is e^2/a^2 , where e is the charge of the ions, and since the number of ions per unit area is of the order of magnitude of $1/a^2$ the total electrostatic force has the order of magnitude of e^2/a^4 . The repulsive forces are of the same order of magnitude, since in equilibrium they balance the Coulomb forces, and the same holds for the maximum of the component in the gliding direction. Hence the gliding strength G should be:

$$G = \gamma \frac{e^2}{a^4}$$

where γ depends on the gliding plane and the gliding direction, and it depends very much on the law for the repulsive forces. Using the results of Lennard-Jones we find that γ may vary between 0.01 and 1. Since a is for most crystals about $6 \cdot 10^{-8}$ cm. we should expect the gliding strength to be of the order of magnitude $2\gamma \cdot 10^{+10}$ dyne/cm.² = $2 \cdot 10^{+3} - 10^5$ gr/mm². The only quantitative determination has been performed by Joffe, Kirpichewa and Levitzky.⁶ They find for the gliding of NaCl along the (011) plane at 0°C a gliding strength of 10^3 gr/mm². Our estimate is made for absolute zero, neglecting the zero point energy. The experiments of Joffé and his collaborators show that the gliding strength increases rapidly with low temperatures. While there are no measurements at temperatures below 0°C we can estimate by extrapolation of Joffé's curves, that for 0°, K the gliding-strength, is of the order of 10^4 gr/mm.², which agrees with our theoretical estimate. Contrary to other statements⁷ we find that Born-Madelung's lattice theory of crystals can account for the observed order of magnitude of the gliding strength.

The influence of the polarizability of the ions on the gliding strength as observed by Buerger is particularly interesting because it presents the only example where the polarizability influences a mechanical property of a regular crystal.

The ions of the crystals investigated by Buerger have the spherical symmetric structure of the atoms of inert gases. In the equilibrium state and during elastic deformation every ion of a crystal of the NaCl type is a center of symmetry. Consequently the polarizability of the ions does not play a rôle either for the equilibrium

⁶ Joffé, M. W., Kirpichewa, and M. A. Levitzky. *Zeit. f. Physik*, Vol. 22, (1924).

⁷ F. Zwicky, *Helvetical physica acta*, Vol. 3, 269 (1930).

energy or for the elastic constants. During gliding however the ions on both sides of the gliding plane are no longer symmetrically surrounded by the other ions. The sum of the electro-static forces exerted by the surrounding ions is no longer zero as in the symmetrical case, but the electric field strength has a finite value of the order of magnitude e/a^2 . Now an ion is an atomic system consisting of a positive nucleus surrounded by negative electrons. If there is no outer field acting on this system the electron distribution is spherically symmetric. An electric field disturbs this symmetry in such a way that the negative electrons are displaced in the direction opposite to the field. In this state the center of gravity of the electrons no longer coincides with the position of the nucleus. The ion is polarized and represents an electric dipole. Such a system can be characterized by its dipole moment μ , which is the product of the total displaced charge and the average displacement. Since this displacement is proportional to and in the direction of the field, the dipole moment induced by a field of the strength K will be proportional to K and we can write:

$$\mu = \alpha K \quad (1)$$

α depends on the structure of the ion and is called the electric polarizability of the ion. This constant plays an important role for the dielectric constant of the crystal and can and has been determined for a large number of ions from measurements of refractive indices. The order of magnitude of α is 10^{-24} cm^3 .

The dipole moment μ is a vector, pointing from the center of gravity of the negative charges towards the nucleus (opposite to the direction of the displacement of the electrons) and has therefore the direction of the field vector K . We have, therefore, for the components:

$$\begin{aligned} \mu_x &= \alpha K_x \\ \mu_y &= \alpha K_y \\ \mu_z &= \alpha K_z. \end{aligned} \quad (1')$$

Due to this electrical polarization of the ions an additional force acts between the two halfcrystals in the state of gliding. This force is the sum of the forces between the electric charges of one halfcrystal and the dipoles of the other halfcrystal. (The forces between the dipoles are of smaller order of magnitude.) To estimate the order of magnitude of this force we have only to consider the ions again in the two planes along which the gliding takes place.

The force acting on a dipole of the moment μ in an electric field is proportional to the rate of change of the field strength, which is of the order of magnitude of e/a^3 , and to the dipole moment which is of the order of magnitude of $\alpha e/a^2$. Hence the additional force per ion is of the magnitude $\alpha e^2/a^5$, and since α is about 10^{-24} cm.³ and a about 10^{-8} cm. we see that this force is of the same magnitude as the Coulomb force e^2/a^2 , and can therefore have an appreciable influence on the gliding-strength.

In order to decide whether the influence of these dipole forces is an increase or a decrease of the gliding strength, we have to calculate the component of the force in the gliding direction. For this purpose let us consider a dipole, represented by a negative charge $-\epsilon$ at the point (xy) and a positive charge $+\epsilon$ at the point $(x+\Delta x, y+\Delta y)$ (Fig. 3). The dipole moment has the components:

$$\begin{aligned}\mu_x &= \epsilon \Delta x \\ \mu_y &= \epsilon \Delta y.\end{aligned}\tag{2}$$

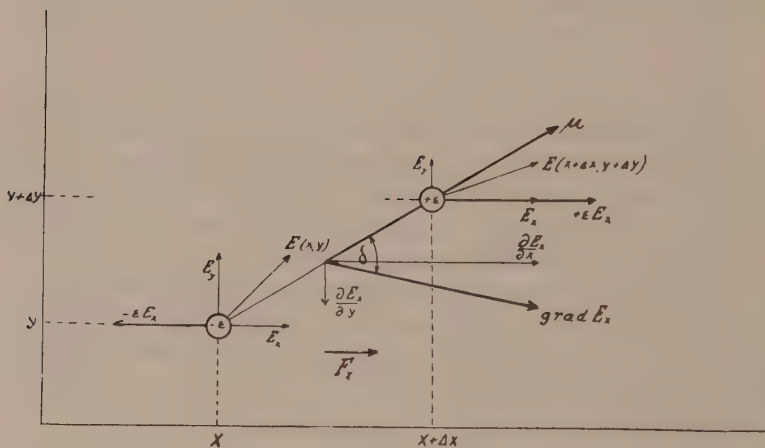


FIG. 3.

This dipole is placed in an electric field with the components, E_x , E_y , which are functions of x and y . The x direction shall be the gliding direction and we will calculate the force on the dipole in the gliding direction. The force on the negative charge $(-\epsilon)$ is evidently $-\epsilon E_x(x, y)$ while the force on the positive charge is $+\epsilon E_x(x+\Delta x, y+\Delta y)$. Since Δx and Δy are small we can develop:

$$E_x(x + \Delta x, y + \Delta y) = E_x(x, y) + \frac{\partial E_x}{\partial x} \Delta x + \frac{\partial E_x}{\partial y} \Delta y$$

The sum $\epsilon E_x(x+\Delta x, y+\Delta y) - \epsilon E_x(x, y)$ gives the total force on the dipole, and we have therefore:

$$F_x = \frac{\partial E_x}{\partial x} \epsilon \Delta x + \frac{\partial E_x}{\partial y} \epsilon \Delta y$$

or

$$F_x = \frac{\partial E_x}{\partial x} \mu_x + \frac{\partial E_x}{\partial y} \mu_y \quad (3)$$

$\delta E_x / \delta x$ and $\delta E_x / \delta y$ can be considered as the x and y components of a vector which is called $\text{grad } E_x$ and a simple calculation shows that (3) can also be written (the scalar product of two vectors)

$$F_x = |\text{grad } E_x| \cdot |\mu| \cos \delta \quad (3')$$

where δ is the angle between the two vectors $\text{grad } E_x$ and μ , and $|\text{grad } E_x|$ and $|\mu|$ are the absolute values of these vectors. This force is positive or negative according to whether the angle δ is smaller or larger than 90° . A positive force acts in the gliding direction and therefore decreases the gliding strength, a negative force however means an increase of the gliding strength.

In the crystal the field E is the Coulomb field of the ions of the other halfcrystal. The dipole moment μ is induced by the field K which is the Coulomb field of the ions of both halfcrystals. Since μ and K have the same direction, δ is also the angle between the vectors E and K . Since a negative ion is always, even during gliding, surrounded in the same way by positive ions just as the negative ions surround a positive one, the direction of E , E_x , $\text{grad } E_x$ and K for a negative ion are all opposite in direction to E , E_x , $\text{grad } E_x$ and K for a positive ion, and consequently the angle δ is the same for each ion. To find the influence of the polarizability on the gliding strength we have therefore to consider any one ion in the gliding plane of one halfcrystal. The polarizability produces an increase or a decrease of the gliding strength according to whether the angle between K and $\text{grad } E_x$ is larger or smaller than 90° . K is the electric field strength on the ion due to all the ions of both halfcrystals, while E_x is the component in the gliding direction of the field strength due to the ions of the other halfcrystal only.

We shall consider the two ways of gliding separately. (1) The gliding along the (001) plane.

E_x and E_y will decrease with increasing distance from the fixed halfcrystal, and E_x will increase with increasing x while E_y will decrease. All these conclusions follow from the fact that the Coulomb forces decrease with the inverse square of the distance, hence the direction and the change of the field is determined by the nearest ion, which in this case is the positive ion in the point C . Hence we have:

$$\frac{\partial E_x}{\partial x} > 0, \quad \frac{\partial E_x}{\partial y} < 0.$$

Therefore the vector grad E_x will be in the fourth quadrant of the system of coordinates.

To find the direction of K , the field due to all ions of both halfcrystals, we can consider it as the sum of three field-strengths, namely the field E due to the ions of the fixed crystal, the field due to the ions in the same layer as the ion, and the field due to the rest of the moving halfcrystal. The ions in the same layer surround the considered ion symmetrically and therefore give no field. The rest of the moving halfcrystal gives a field which is equal and opposite to the field E at the point A . Hence:

$$\begin{aligned} K_x &= E_x \\ K_y &= E_y(x, y) - E_y(A). \end{aligned}$$

Since $\delta E_y / \delta x < 0$ and $\delta E_y / \delta y < 0$ we always have $E_y(x, y) < E_y(A)$. Hence:

$$\begin{aligned} K_x &> 0 \\ K_y &< 0. \end{aligned}$$

Whence the vector K is also in the fourth quadrant of the system of coordinates, and the angle δ between the vectors K and grad E_x is necessarily smaller than 90° . Consequently, *the polarizability of the ions always decreases the gliding strength along the (001) plane.* This holds independent whether there is a lift or not.

(2) The gliding along the (011) plane.

In this case the ions move in the (001) plane (Fig. 5) and again the vectors E , K , grad E_x have no component normal to this plane. The path of the ion from A to B is certainly not a straight line, since the ion cannot penetrate the ion at the point C . It is more natural to assume that the path is approximately a circle around the point C . We choose the x direction in the direction of gliding and the y

direction normal to the fixed halfcrystal. The maximum force will again be reached for $x = a/8\sqrt{2}$. We consider a negative ion. From the crystallographic arrangement we conclude, that for $x \leq a/8\sqrt{2}$ we have:

$$E_x < 0 \quad \frac{\partial E_x}{\partial x} < 0$$

$$E_y > 0 \quad \frac{\partial E_x}{\partial y} > 0.$$

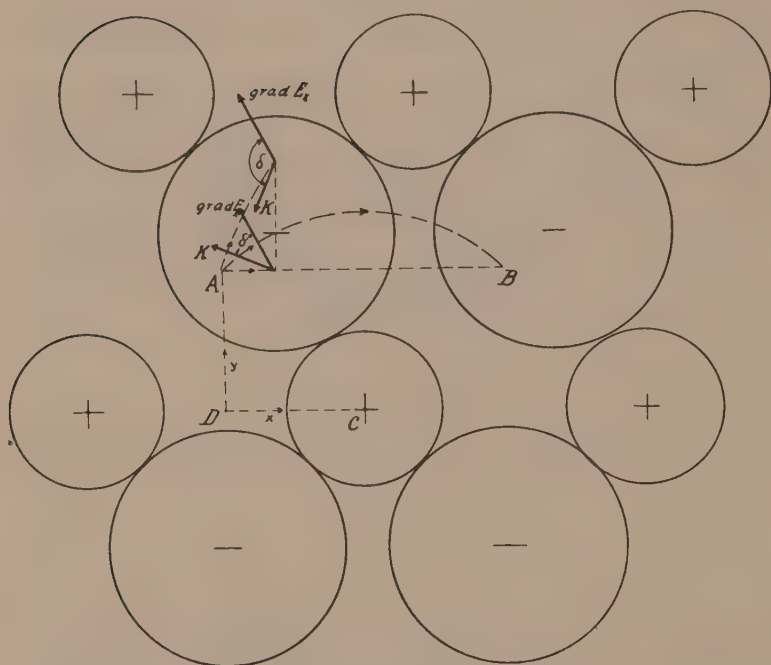


FIG. 5.

Hence the vector $\text{grad } E_x$ is in the second quadrant of the system of coordinates. The vector K is again:

$$K_x = E_x < 0$$

$$K_y = E_y(x, y) - E_y(A).$$

If the path would be a straight line we would necessarily have $E_y(x, y) > E_y(A)$ and hence $K_y > 0$. For this case the vector K is also in the second quadrant and the angle δ is smaller than 90° .

The polarizability would therefore produce a decrease of the gliding strength. However, there must be a lift connected with the gliding along the (011) plane. For a very large lift $E_y(x, y)$ becomes very small, hence $K_y = -E_y(A) < 0$, and the vector K is now in the third quadrant. Therefore, there exists the possibility that with lift the angle δ is larger than 90° , and that the polarizability of the ions produces an increase of the gliding strength along the (011) plane. There will be a path between A and B along which the angle δ is 90° and along which the polarizability of the ions will not influence the gliding strength. If the actual path lies below this critical path, the polarizability results in a decrease of the gliding strength, but if the actual path lies above it the polarizability increases it.

In order to determine this critical path we need to know the value of E_x and E_y . They can be calculated by a method given by Madelung. Frenkel has given the electrostatic potential of a half-crystal limited by a (011) plane, and from it we find as a first approximation:

$$E_x = -\frac{32\pi e}{a^2} \cdot \frac{1}{\sqrt{3}} \cdot \frac{e^{-2\pi y/a\sqrt{3}}}{1 - e^{-\pi\sqrt{3}/2}} \cdot \sin \frac{4\pi}{a\sqrt{2}} x$$

$$E_y = \frac{16\pi e}{a^2\sqrt{2}} \cdot \frac{e^{-2\pi y/a}}{1 + e^{-\pi\sqrt{1/2}}} - \frac{32\pi e}{a^2\sqrt{2}} \cdot \frac{e^{-2\pi y/a\sqrt{3}}}{1 - e^{-\pi\sqrt{3}/2}} \cdot \cos \frac{4\pi}{a\sqrt{2}} x$$

where x and y are the coordinates with respect to the point D . The dipole force vanishes according to (1') and (3) if

$$K_x \frac{\partial E_x}{\partial x} + K_y \frac{\partial E_x}{\partial y} = 0 \quad (4)$$

where $K_x = E_x$ and

$$K_y = E_y - E_y(A) = \frac{16\pi e}{a^2\sqrt{2}} \cdot \frac{1}{1 + e^{-\pi\sqrt{1/2}}} [e^{-2\pi y/a} - e^{-\pi\sqrt{1/2}}]$$

$$- \frac{32\pi e}{a^2\sqrt{2}} \cdot \frac{1}{1 - e^{-\pi\sqrt{3}/2}} \left[e^{-2\pi y/a\sqrt{3}} \cos \frac{4\pi}{a\sqrt{2}} x - e^{-\pi\sqrt{3}/2} \right].$$

Introducing these expressions in (4) we find, after a rather long but elementary calculation, that the dipole force vanishes for $x=0$ and if

$$e^{-2\pi y/a\sqrt{3}} \cos \frac{4\pi}{a\sqrt{2}} x - \frac{3}{2} \frac{1 - e^{-\pi\sqrt{3}/2}}{1 + e^{-\pi\sqrt{1}/2}} \cdot e^{-2\pi y/a}$$

$$= 3e^{-\pi\sqrt{3}/2} - \frac{3}{2} \frac{1 - e^{-\pi\sqrt{3}/2}}{1 + e^{-\pi\sqrt{1}/2}} \cdot e^{-\pi\sqrt{1}/2}$$

or

$$e^{-2\pi y/a\sqrt{3}} \cos \frac{4\pi}{a\sqrt{2}} x - 1.325e^{-2\pi y/a} + 0.0798 = 0.$$

Since $y > a/4\sqrt{2}$ the first term is always very much smaller than the two others and can therefore be neglected, and we find that the dipole force vanishes if:

$$y = -\frac{a}{2} \log \text{nat.} \frac{0.0798}{1.325} = 0.447, \quad a = \frac{a}{4}\sqrt{2} + 0.093a.$$

Consequently, the electric polarization of the ions increases or decreases the gliding strength according to whether the lift in the point of maximum gliding force is smaller or larger than $0.093a$.

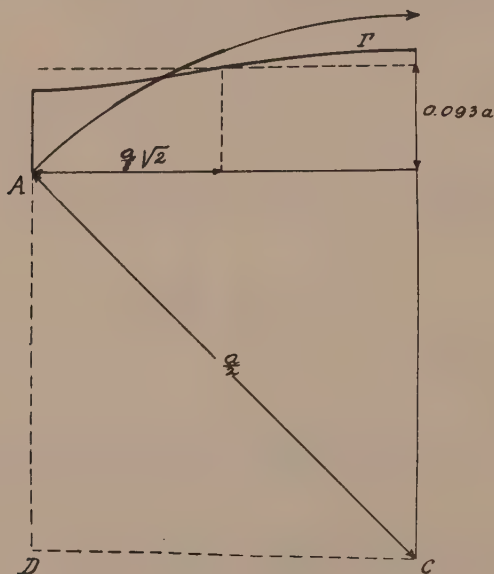


FIG. 6.

Fig. 6 shows the curve Γ along which the dipole force vanishes (calculated without neglecting the first term). The forces acting between the ions during gliding are not large enough to produce an

appreciable compression of the ions. Hence we must assume that the path of the ion must be a circle with C as center. The periodicity of the crystal structure leads to the conclusion that the maximum gliding force occurs for a shift $x = a/8\sqrt{2}$. The figure shows that at this point the lift is larger than $0.093a$. A more careful consideration of the repulsive forces shows that the maximum gliding force may occur for a shift $x < a/8\sqrt{2}$ but still at a point near the curve Γ . We conclude therefore that: *The polarizability of the ions has a very small influence on the gliding strength along the (011) plane.* Whether it is an increase or a decrease depends on the law governing the repulsive forces.

SUMMARY

The gliding strength of crystals cannot accurately be calculated since it depends largely on the unknown law for the repulsive forces between the ions. The order of magnitude of the observed gliding strength is in agreement with the estimated theoretical value. The experiments show that for crystals with ions of small polarizability the gliding strength along the (011) plane is smaller than along the (001) plane.

The theory leads to the conclusion that the electric polarizability of the ions decreases the gliding strength along the (001) plane but does not appreciably change the gliding strength along the (011) plane.

This consideration explains the observation (Fig. 2) of Buerger that crystals whose ions have a large polarizability glide along the (001) plane.

FURTHER STUDIES IN THE AMPHIBOLE GROUP

A. N. WINCHELL, *University of Wisconsin.*

1. INTRODUCTION

At the time of an earlier study of the amphibole group¹ it was considered by the writer (and others) that experimental work carried out at the Geophysical Laboratory had demonstrated that the same molecule, namely, MgSiO_3 , could be made to crystallize either as a pyroxene or as an amphibole. The type-formula of the amphiboles being thus apparently established, formulas of the same type were deduced from the published analyses for the other amphiboles, disregarding their tenor of water. By a remarkable study of tremolite by *X*-ray methods, Warren² has recently demonstrated that the water cannot be neglected; since water is not a constituent of pyroxenes, it follows that the same molecules are not found in pyroxenes and amphiboles, and that the molecules of the amphibole group are more complicated than those of the pyroxenes. Warren has established the composition of tremolite as $\text{H}_2\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{24}$; starting with this type-formula, the laws of isomorphism, as modified by *X*-ray studies, lead to Warren's conclusion³ that other amphibole molecules include:

Actinolite	$\text{H}_2\text{Ca}_2\text{Fe}_5\text{Si}_8\text{O}_{24}$
Kupfferite	$\text{H}_2\text{Mg}_7\text{Si}_8\text{O}_{24}$
Grunerite	$\text{H}_2\text{Fe}_7\text{Si}_8\text{O}_{24}$
Hornblende	$\text{H}_2(\text{Ca, Na, K})_{2-3}(\text{Mg, Fe, Al})_5(\text{Si, Al})_8\text{O}_{24}$

The peculiar feature of the formula assigned to hornblende, namely, the variable number (2-3) of (Ca, Na, K) atoms is explained by Warren as follows:

"In the tremolite structure [space-lattice] there are seven metal atoms (2 Ca and 5 Mg), and in addition a vacant position where a single atom such as Na or K might find position. Replacements are of two types: (a) such that the number of metal atoms remains 7, $\text{Mg} = \text{Fe}$, $\text{Ca} = \text{Mg}$, $(\text{Mg, Si}) = (\text{Al, Al})$; (b) where the vacant position in the tremolite structure is filled by Na or K and the number

¹ *Am. Jour. Sci.*, CCVII, 1924, pp. 287-310; also "Elements of Optical Mineralogy, Part II," John Wiley and Sons, New York, 1927, pp. 198-216.

² *Zeit. Kryst.*, LXXII, pp. 42-57.

³ *Zeit. Kryst.*, LXXII, 1930, pp. 493-517.

of metal atoms is increased from 7 to 8, $\text{Si} = (\text{Al}, \text{Na})$, $\text{Ca} = (\text{Na}, \text{Na})$."

It is the purpose of this article to discuss the relations between variations in optic properties and variations in composition in various parts of the amphibole group on the basis of the newly established type-formula for the group. An attempt will be made, also, to deduce definite formulas for the chief molecules of hornblende to replace the indefinite formula proposed by Warren.

It is interesting to note that B. Gossner⁴ deduced the correct formula of tremolite as early as 1924, although he expressed it in the unfamiliar form: $2\text{SiO}_3 \cdot \text{Ca} \cdot 4\text{SiO}_3 \cdot \text{Mg} \cdot [2\text{SiO}_2 - \text{MgO}_2\text{H}_2]$. It is a pleasure to call attention to the fact that Schaller⁵ obtained the correct formula of tremolite as early as 1916. Still more important in relation to the present study is the recent article by W. Kunitz,⁶ who also deduced the correct formulas for tremolite, actinolite, kupfferite and grunerite, but considered that hornblende and arfvedsonite formulas have only 22 atoms of oxygen. Kunitz made numerous analyses of amphiboles on samples, some of whose optic properties he measured, so that his study adds much to our knowledge of the subject under consideration in this article. In some cases his graphs are almost unmodified by the present results; in other cases new results are obtained.

2. THE ANTHOPHYLLITE SERIES

The anthophyllite series differs from all other amphiboles, not only in simplicity of composition, due to the absence of Ca, Al, and Na atoms, but also in possessing orthorhombic symmetry. Kunitz⁷ regards the difference of symmetry as of little importance and unites the anthophyllite series with the cummingtonite series. The comparative X-ray study of anthophyllite, cummingtonite and tremolite made by K. Johansson⁸ shows clearly that the difference in symmetry is a fundamental property inherent in the space-lattices and should not be disregarded. X-ray patterns of anthophyllite and of tremolite made at the University of Wisconsin by the powder method are clearly different, while patterns of tremolite and hornblende are almost identical.

⁴ *Zeit. Kryst.*, **LX**, 1924, p. 368.

⁵ *U. S. Geol. Surv., Bull.* **610**, 1916, p. 133.

⁶ *N. Jahrb. Min., Bl. Bd.*, **LX**, A, 1930, pp. 171-250.

⁷ *Op. cit.*, p. 187.

⁸ *Zeit. Kryst.*, **LXXIII**, 1930, pp. 31.

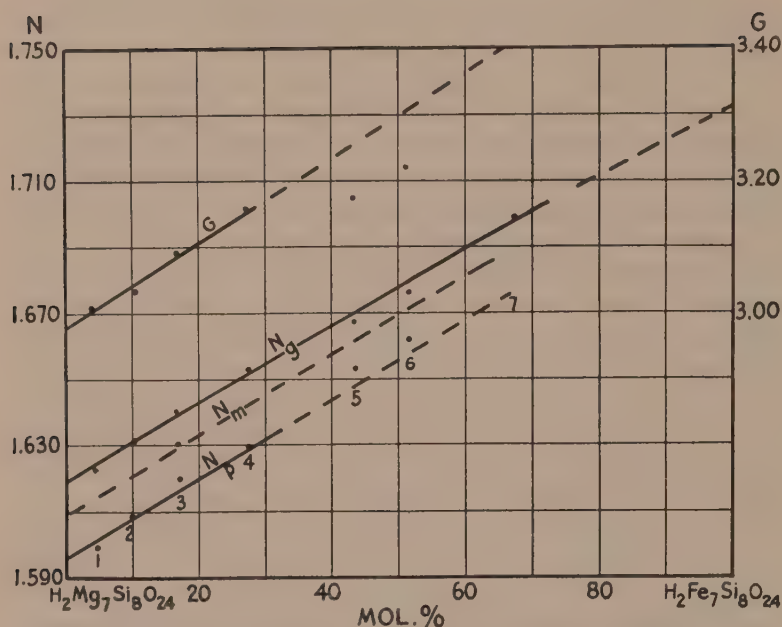


FIG. 1. Variations of composition and properties in the anthophyllite series.

REFERENCES FOR FIG. 1—ANTHOPHYLLITE SERIES

1. Anthophyllite (Valleite), Edwards, N. Y. W. Kunitz: *N. Jahrb. Min. Bl.-Bd.*, **LX**, 1930, pp. 188, 189 and 244. Pale yellowish thin-lamellar crystals.
2. Anthophyllite, Miask. W. Kunitz: *loc. cit.* Brownish and greenish crystals.
3. Anthophyllite, Franklin, N. C. S. L. Penfield: *Am. Jour. Sci.*, **CXL**, 1890, p. 394.
4. Anthophyllite, Kjermerud. W. Kunitz: *loc. cit.* Brown elongated crystals.
5. Anthophyllite (Gedrite), Träskböle, Orijarvi. P. Eskola: *Bull. Com. Geol. Finlande*, **XL**, 1915, p. 176. Brown crystals. N_g as corrected on p. 279.
6. Anthophyllite (Gedrite), Träskböle, Orijarvi. P. Eskola: *loc. cit.* Brown crystals. N_g as corrected on p. 279.
7. Anthophyllite, Mesabi Range, Minn. Incomplete analysis by C. R. Wise: $\text{SiO}_2=42.98$, $\text{Al}_2\text{O}_3=2.14$, $\text{Fe}_2\text{O}_3=1.50$, $\text{FeO}=37.82$, $\text{MgO}=5.91$, $\text{CaO}=1.50$, $\text{H}_2\text{O}=5.23$, Total=97.08. Parallel extinction and $N_g=1.698$ as measured by A. N. Winchell.

The relations between composition and optic properties (and density) in the anthophyllite series are shown in Fig. 1. The two samples described by Eskola from Finland show clearly that about 7.5 per cent Al_2O_3 lowers the specific gravity of anthophyllite about 0.8 and the indices of refraction from 0.004 (N_g) to nearly 0.01 (N_m). Unfortunately no member of this series very high in iron has

been studied as yet, since the "ferroanthophyllite" of Shannon⁹ must be assigned to actinolite,¹⁰ as shown by the following facts. It contains about 11 per cent CaO, a fact confirmed by test made by Sidney Schafer on a small fragment of the original material kindly supplied through the courtesy of Dr. Wetmore of the U. S. National Museum. It shows parallel extinction between crossed nicols of groups of fibers in any position and also of single fibers in the usual position, but V. E. Barnes reports that a single tiny fiber when turned on its axis to a suitable position shows an extinction angle of about 10° , although it shows parallel extinction in some positions. He also reports an approximate value of the optic angle, $2V$, as 74° about X . Finally, the X-ray pattern given by the sample is practically identical with that given by tremolite and distinctly different from that given by anthophyllite as shown by the patterns reproduced in Fig. 2.

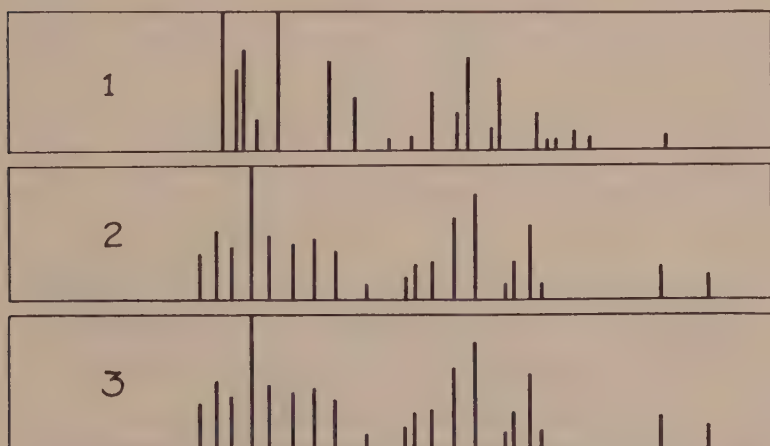


FIG. 2. X-ray patterns of: (1) anthophyllite from Medway, Mass., (2) "ferroanthophyllite," Idaho = type material as described by E. V. Shannon: *Proc. U. S. Nat. Mus.*, LIX, 1921, p. 397, (3) tremolite, No. 1310, Univ. Wis.

3. THE CUMMINGTONITE SERIES

The cummingtonite series is chemically equivalent to the anthophyllite series, but crystallographically it is monoclinic instead of orthorhombic. The series consists of kupfferite ($H_2Mg_7Si_8O_{24}$),

⁹ *U. S. Nat. Mus. Proc.*, LIX, 1921, pp. 397-401.

¹⁰ It was referred to actinolite by Kunitz because of its tenor of CaO: *loc. cit.*, pp. 193, 194.

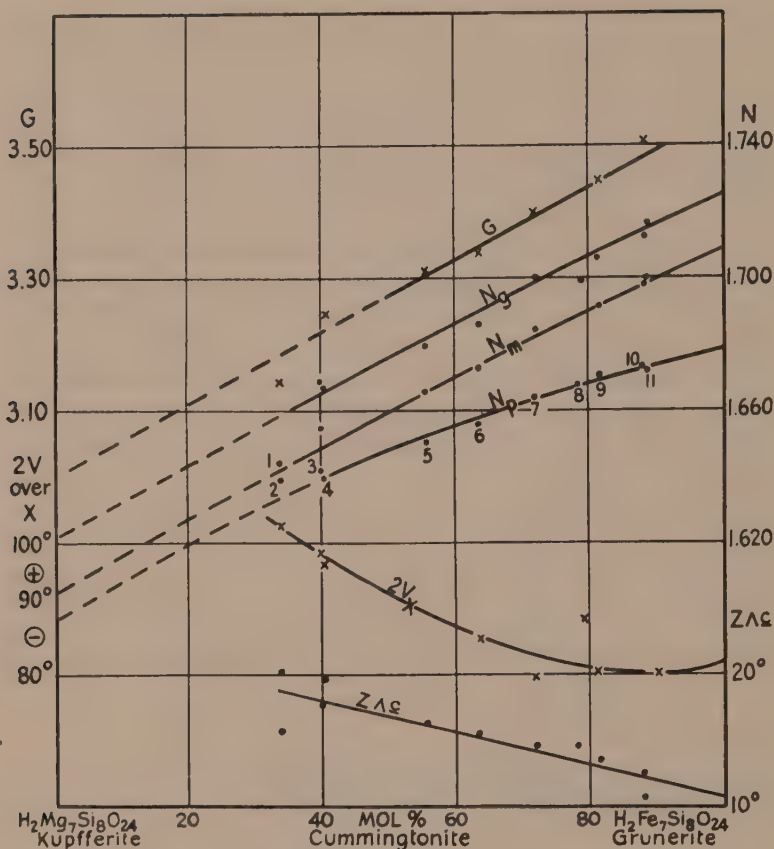


FIG. 3. Variations of composition and optic properties in the cummingtonite series.

REFERENCES FOR FIG. 3—CUMMINGTONITE SERIES

1. Cummingtonite, Orijarvi, Finland. P. Eskola: *Bull. Com. Geol. Finlande*, **XL**, 1915, pp. 112, 222.
2. Cummingtonite, Kongsberg, Norway. A. Des Cloizeaux: *Nouv. Rech. Mem.*, **XVIII**, 1867, from Dana: *System Mineralogy*, 1892, p. 390.
3. Cummingtonite, Träskböle, Finland. P. Eskola: *op. cit.*, p. 182.
4. Cummingtonite, Röbergsgruvan, Sweden. N. Sundius: *Geol. För. Förh.*, Stockholm, **XLVI**, 1924, p. 154.
5. Cummingtonite, Ö. Silvergruvan, Sweden. N. Sundius: *loc. cit.*, p. 154.
6. Cummingtonite, Tunaberg, Sweden. K. Johansson: *Zeit. Kryst.*, **LXXIII**, 1930, p. 31.
7. Grunerite, Strömshult, Sweden. J. Palmgren: *Bull. Geol. Inst. Univ. Upsala*, **XIV**, 1917, p. 109.
8. Grunerite, ("Cummingtonite") Krivoi Rog, Russia. Polovinkina: *Mem. Soc. Russe Mineral.*, **LIII**, 1924, p. 179, from *N. Jahrb. Mineral.*, A, 1927, I, p. 39.

9. Grunerite ("Silvbergite"), Silvberg, Sweden. N. Sundius: *op. cit.*, p. 154.
10. Grunerite (Dannemorite), Dannemora, Sweden. N. Sundius: *op. cit.*, p. 154.
11. Grunerite, Collobrières, France. S. Kreutz: *Sitzb. Akad. Wiss. Wien*, **CXVII**, 1908, p. 875.

cummingtonite $[\text{H}_2(\text{Mg}, \text{Fe})_7\text{Si}_8\text{O}_{24}]$ and grunerite $(\text{H}_2\text{Fe}_7\text{Si}_8\text{O}_{24})$; a variety containing considerable manganese has been called dannemorite. Samples from nature containing more than 70 per cent of the magnesium molecule are very rare and no careful studies have been made on such material. Furthermore, the only careful study¹¹ made of an artificial product supposed to be the pure magnesian monoclinic amphibole includes no analysis of the product, which was so fine-grained that accurate optical measurements were impossible. Consequently, the properties of kupferite can only be inferred by extrapolation. As stated in the discussion of the anthophyllite series the writer can see no justification for disregarding crystallographic differences and combining the anthophyllite and cummingtonite series, even though it may be true that they are very nearly the same in their refractive indices. These two series seem to furnish a good example of isodimorphism; an example in which the magnesian member is more stable in the orthorhombic phase, while the ferrous iron member is more stable in the monoclinic phase. The relations between composition and properties are shown in Fig. 3.

It is worthy of note that 10.95 per cent MnO found in the mineral from Dannemora, Sweden (No. 10) makes no appreciable differences in the physical characters, as shown by the graph. On the other hand, about 5 per cent CaO (which means about 40 per cent of the actinolite molecule), found in cummingtonite from Mansjö Mt. by H. von Eckerman (*Geol. För. Förh.*, **XLIV**, 1922, p. 303) and in cummingtonite from Brunsjögruvan by N. Sundius (*op. cit.*, p. 154) decreases the indices of refraction nearly .01, and apparently decreases the optic angle measured about X considerably.

4. THE TREMOLITE-ACTINOLITE SERIES

The writer has given elsewhere¹² the evidence available in 1924 which tends to show that Mg and Fe may be replaced by Ca in monoclinic amphiboles in any amount from 0 to 50 molecular per cent. However, although such a possibility seems to exist, it is

¹¹ *Am. Jour. Sci.*, **CLXXII**, 1906, pp. 403, 431.

¹² *Am. Jour. Sci.*, **CCVIII**, 1924, p. 287.

clear that the usual condition is that Ca is either absent (or negligible) or present in about the ratio of 2 to 5, with the important exception that this ratio is commonly changed to about 2 to 4 in hornblende by the replacement of one atom of Mg by one atom of Al (with simultaneous replacement of one atom of Si by one atom of Al).

Accordingly, there is a fairly definite tremolite molecule the formula of which is $\text{H}_2\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{24}$, as shown by Warren.¹³ Since the magnesium may be replaced in any proportion by ferrous iron there is a definite and continuous series from tremolite, to actinolite, $\text{H}_2\text{Ca}_2\text{Fe}_5\text{Si}_8\text{O}_{24}$. Analyses indicate that minerals of this series usually contain a moderate tenor (20–30 mol. per cent) of other amphibole molecules, including $\text{H}_2\text{NaCa}_2\text{Mg}_5\text{AlSi}_7\text{O}_{24}$ and the molecules of the cummingtonite series, but a higher tenor is rare. On account of these other molecules, the diagram (Fig. 4) expressing the relations between composition and properties in the tremolite-actinolite series shows a range of possible variation in the properties for any given molecular percentage of the chief molecules. The accessory molecules seem to be especially important in determining the extinction angle ($Z \wedge c$). Johansson¹⁴ reports measuring the extinction angle in "grammatite" (=tremolite No. 6) in the acute angle β ; this is plotted with the other results on the assumption that it is a misstatement.

About 15 molecular per cent of the glaucophane molecule lowers the indices of refraction about 0.005, as shown in sample No. 18.

The reasons for including Shannon's "ferroanthophyllite" as actinolite (No. 19) have been given in the discussion of the anthophyllite series.

¹³ *Zeit. Kryst.*, LXXII, 1929, p. 42.

¹⁴ *Zeit. Kryst.*, LXXIII, 1930, p. 31.

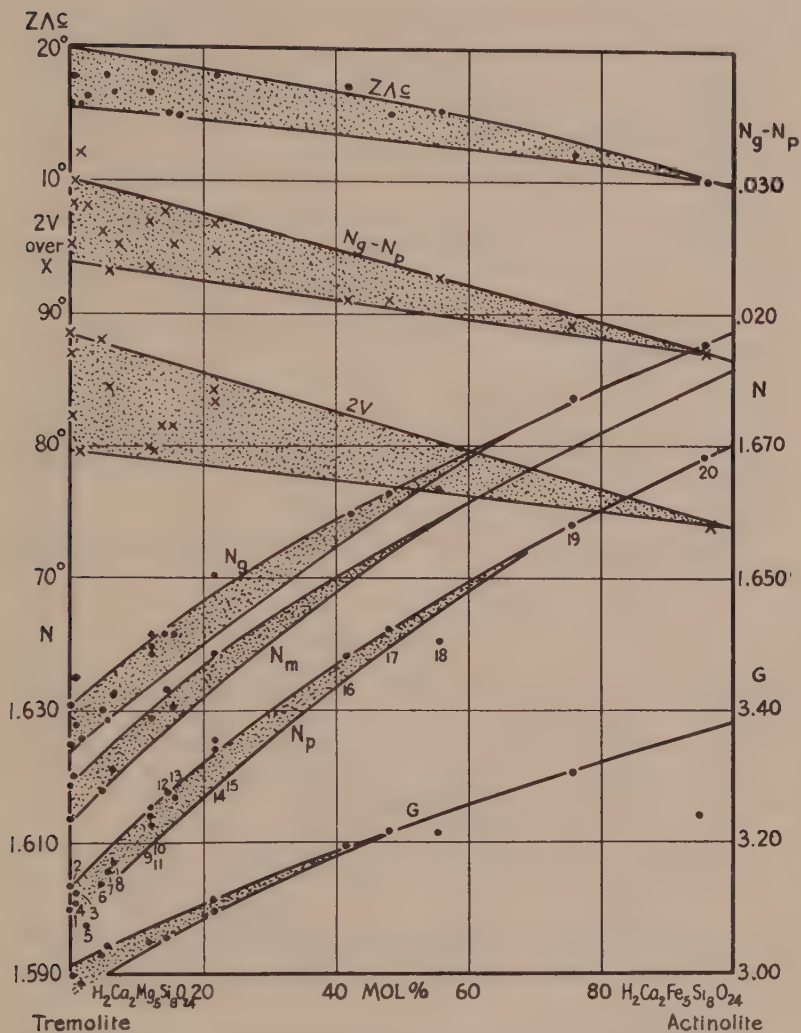


FIG. 4. Variations of composition and properties in the tremolite-actinolite series.

REFERENCES FOR FIG. 4—TREMOLITE-ACTINOLITE SERIES

1. Tremolite, Richville, N. Y. Optic data given by W. E. Ford: *Am. Jour. Sci.*, **CLXXXVII**, 1914, p. 179; analysis given by S. L. Penfield and F. C. Stanley: *Am. Jour. Sci.*, **CLXXIII**, 1907, p. 31. Optic data also given by S. Kreutz: *Sitzb. Akad. Wiss. Wien.*, **CXVII**, 1908, p. 928.
2. Tremolite, Ossining, N. Y. Analysis given by E. T. Allen and J. K. Clement: *Am. Jour. Sci.*, **CLXXVI**, 1908, p. 101. On fragments of the original material kindly supplied by Dr. H. E. Merwin of the Geophysical Laboratory, Virgil E. Barnes has

obtained by the double variation method of Emmons the following indices: $N_o = 1.6307$ D, $N_m = 1.6183$, $N_p = 1.6024$; $N_o - N_p = 0.0273$, $(-)2V = 83^\circ$ calc.; $F - C = 0.009$ (N_m); also $Z \wedge c = 15\frac{1}{2}^\circ$, $2V = 82^\circ$ obs.

3. Tremolite, Lee, Mass. Analysis by Penfield and Stanley: *op. cit.* Optic data by W. E. Ford: *op. cit.*

4. Tremolite, Switzerland. S. Kreutz: *Sitz. Akad. Wiss. Wien.* **CXVII**, 1908, p. 925.

5. "Nephrite," Bahia, Brazil. Optic data by H. E. Merwin and analysis by H. S. Washington: *Pan-Amer. Geol.*, **XXXVII**, 1922, p. 198.

6. "Grammatite," Kaveltorp. Sweden. K. Johansson: *Zeit. Kryst.*, **LXXIII**, 1930, p. 31.

7. Tremolite, Edwards, N. Y. W. Kunitz: *N. Jahrb. Min.*, Bl. Bd., **LX**, 1930, p. 171. A very similar analysis of tremolite from Edwards, N. Y., given by E. T. Allen and J. K. Clement: *op. cit.*

8. Actinolite, Pierrepont, N. Y. S. Kreutz: *op. cit.* (Analysis by Haefcke). Virgil E. Barnes has obtained on actinolite from Pierrepont, N. Y. the following data: $N_o = 1.6301$ D, $N_m = 1.6201$, $N_p = 1.6067$; $N_o - N_p = 0.0237$; $2V = 82^\circ$ calc., 82° obs. $Z \wedge c = 18^\circ$.

9. Actinolite, Greiner, Switz. S. Kreutz: *op. cit.*

10. Actinolite, Japan. *Jour. Pet. Mineral. Ore Dep.*, **I**, 1929, p. 73. From an abstract.

11. Actinolite, Arendal. W. Kunitz: *op. cit.*

12. Actinolite, Greiner, Tyrol. Analysis by Penfield and Stanley: *op. cit.* Optic data by W. E. Ford: *op. cit.*

13. Actinolite, Russell, N. Y. Analysis by Penfield and Stanley: *op. cit.* Optic data by W. E. Ford: *op. cit.*

14. Actinolite, Pierrepont, N. Y. Analysis by Penfield and Stanley: *op. cit.* Optic data by W. E. Ford: *op. cit.* Birefringence given by Ford ($N_o - N_p = 0.0236$) does not check values of $N_o - N_p$; probably should be 0.0266.

15. Actinolite ("black hornblende"), Snarum. S. Kreutz: *op. cit.*

16. Actinolite, New Hampshire. W. Kunitz: *op. cit.*

17. Actinolite, Rhode Island. W. Kunitz: *op. cit.*

18. Actinolite ("Winchite"), Piz Valesa. W. Kunitz: *op. cit.*

19. Actinolite, Nordmark. W. Kunitz: *op. cit.*

20. "Ferroanthophyllite," Idaho. E. V. Shannon: *Proc. U. S. Nat. Mus.*, **LIX**, 1921, p. 397.

The only known modern data combining analyses with optic measures omitted from the diagram are the following:

"Hornblende" (= Tremolite), Russell, N. Y. S. Kreutz: *op. cit.* Calculations into amphibole molecules not satisfactory.

Actinolite, Kupferberg. W. Kunitz: *op. cit.* The published weight analysis does not check the published molecular analysis as to iron.

Actinolite, Kragerö, Norway. Analysis by Penfield and Stanley: *op. cit.* Optic data by W. E. Ford: *op. cit.* Indices are high (because of TiO_2 ?).

Actinolite, Kragerö, Norway. Analysis by H. S. Washington and optic data by H. E. Merwin: *Am. Mineral.*, **VIII**, 1923, p. 66. Indices are high (because of TiO_2 ?).

Actinolite, Berkeley, Calif. W. C. Blasdale: *Bull. Dept. Geol. Univ. Calif.*, II, 1902, p. 327. No determination of Fe_2O_3 , MnO nor TiO_2 .

"Hornblende" (= Actinolite), Hebrides. L. Duparc and F. Pearce: *Bull. Soc. Fr. Min.*, XXXI, 1908, p. 109. Calculations into amphibole molecules not satisfactory.

5. THE $\text{H}_2\text{CA}_2\text{MG}_5\text{SI}_8\text{O}_{24}$ — $\text{H}_2\text{NACA}_2\text{MG}_5\text{ALSI}_7\text{O}_{24}$ SERIES

Several of the samples studied optically by V. E. Barnes¹⁵ have been analyzed recently by R. B. Ellestad of the Rockefeller Laboratories with results as follows:

	1	2	3	4	5	6
SiO_2	56.87	46.46	46.22	46.03	54.54	47.16
Al_2O_3	1.26	13.70	4.13	12.03	1.40	6.19
Fe_2O_3	0.11	0.38	0.36	1.18	5.03	5.64
FeO	2.26	0.99	0.85	2.22	8.17	11.64
MgO	22.47	20.48	20.27	20.16	16.40	12.75
CaO	14.09	12.57	12.73	12.84	8.33	9.53
Na_2O	0.75	2.84	2.75	2.66	2.93	3.05
K_2O	0.15	0.57	0.58	0.80	0.66	1.41
H_2O	1.53	1.35	1.36	0.99	1.65	1.16
F	0.21	0.26	0.33	0.25	0.16	0.20
TiO_2	0.13	0.04	0.05	0.48	0.31	0.37
MnO	0.13	0.05	0.06	0.05	0.32	0.38
Total	99.76	99.69	99.69	99.69	99.90	99.48
$\text{O} = \text{F}_2$	0.09	0.11	0.14	0.11	0.07	0.08
Sum	99.87	99.58	99.55	99.58	99.83	99.40

1. "Edenite," Edenville, N. Y.
2. "Pargasite," Edenville, N. Y.
3. "Pargasite," Amity, N. Y.
4. "Pargasite," Warwick, N. Y.
5. "Hornblende," Ottawa, Canada.
6. "Hornblende," Eganville, Ont.

A study of these analyses revealed that one of them (the pargasite from Amity, N. Y.) represents a chemically rare type of amphibole which consists very largely of one molecule; indeed, it contains about 80 molecular per cent of $\text{H}_2\text{NACA}_2\text{MG}_5\text{ALSI}_7\text{O}_{24}$ with about 14 per cent of $\text{H}_2\text{CA}_2\text{MG}_5\text{SI}_8\text{O}_{24}$. It may therefore serve to establish approximately the optical characters of a molecule which is not ordinarily present in hornblende, but is a possibility in every case. The discovery of other samples of amphibole representing ap-

¹⁵ *Am. Mineral.*, XV, 1930, p. 393.

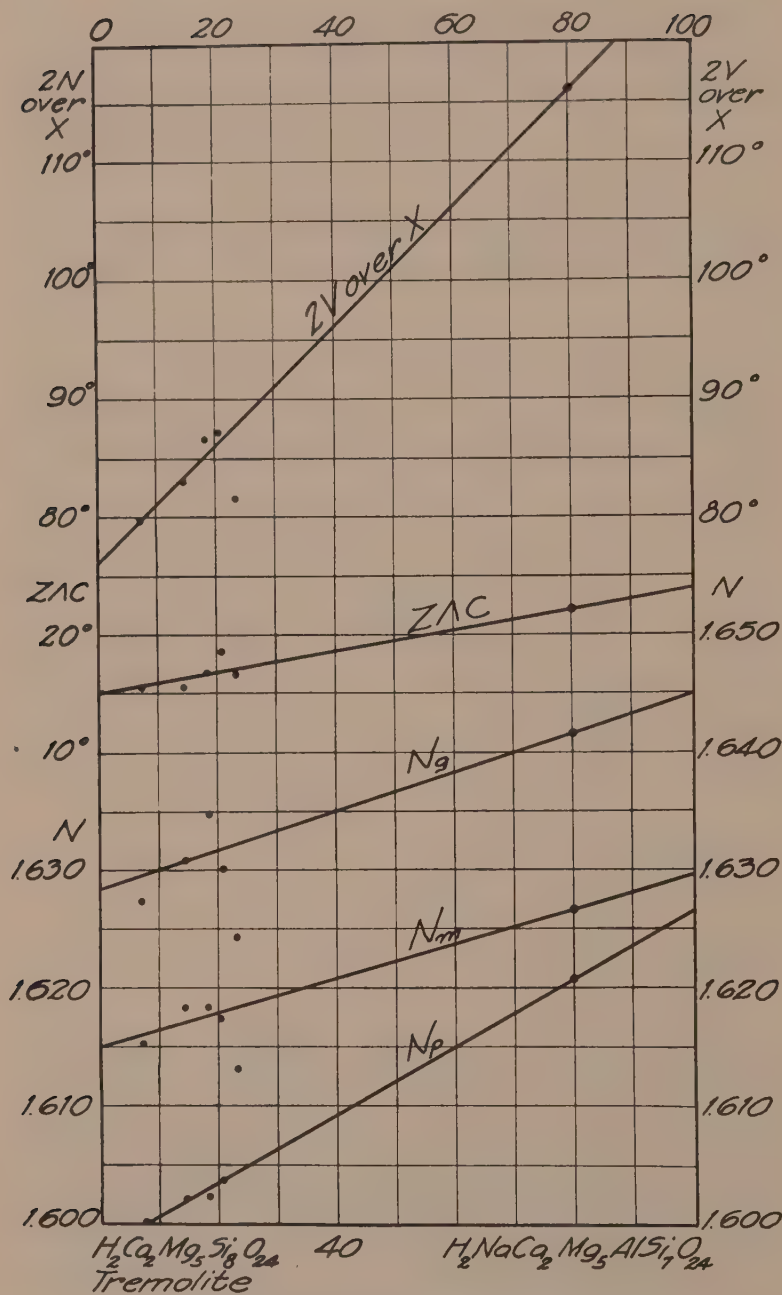


FIG. 5. Variations of composition and properties in the tremolite, $H_2Ca_2Mg_5Si_8O_{24} - H_2NaCa_2Mg_5AlSi_7O_{24}$ series.

proximately pure molecules may be expected to gradually disclose the full relations between the composition and the optical properties in this extremely complex system. The relations between properties and composition in the tremolite — $\text{H}_2\text{NaCa}_2\text{Mg}_5\text{AlSi}_7\text{O}_{24}$ series are shown in Fig. 5. It is clear that the substitution of Al, Na for Si has a very marked effect upon the optic properties. It raises the indices of refraction, and increases the extinction angle, but the most remarkable effect is on the optic angle which is changed from about 75° to more than 120° about X , thus changing the optic sign. It is clear from a study of the optic properties of amphiboles moderately rich in the molecule $\text{H}_2\text{NaCa}_2\text{Mg}_4\text{Al}_3\text{Si}_6\text{O}_{24}$ that this molecule produces similar effects. It seems that the substitution of Al, Na for Si produces much more effect on the optic properties than does the substitution of Al, Al for Mg, Si.

6. THE COMMON HORNBLLENDE SYSTEM

In an earlier study¹⁶ of the amphibole group it was shown that the ratio between Ca and Mg+Fe is not the same in the hornblende as in the tremolite-actinolite system. This difference seems to be due to the replacement of some Mg atoms by Al atoms, the total valencies remaining balanced by means of the simultaneous replacement of Si atoms by Al atoms. Expressed in groups containing oxygen, MgSiO_3 may be replaced by AlAlO_3 in hornblende just as in pyroxene, biotite and chlorite. This relationship between tremolite and hornblende is not easily derived from analyses because there seems to be no simple gradation from the tremolite molecule, $\text{H}_2\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{24}$, to a corresponding hornblende molecule, $\text{H}_2\text{Ca}_2\text{Mg}_4\text{Al}_2\text{Si}_7\text{O}_{24}$, representing only the replacement of MgSiO_3 by AlAlO_3 ; on the contrary, a different type of replacement, first discovered and explained by Warren,¹⁷ seems to accompany the replacement of MgSiO_3 by AlAlO_3 in hornblende with surprising frequency; this is the replacement of Si by (Na)Al, the extra Na atom taking a place in the space lattice which is otherwise unoccupied. Thus it comes about that the gradation from tremolite to magnesian hornblende is not from $\text{H}_2\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{24}$ to $\text{H}_2\text{Ca}_2\text{Mg}_4\text{Al}_2\text{Si}_7\text{O}_{24}$, but from $\text{H}_2\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{24}$ to $\text{H}_2\text{NaCa}_2\text{Mg}_4\text{Al}_3\text{Si}_6\text{O}_{24}$. A sample of hornblende from Montville, N. J., analyzed by L. G. Eakins¹⁸ is composed of this molecule to the extent of

¹⁶ *Am. Jour. Sci.*, CCVII, 1924, p. 287.

¹⁷ *Op. cit.*

¹⁸ *U. S. Geol. Surv. Bull.* 64, 1890. p. 40.

83 per cent and has also 10 per cent of $\text{H}_2\text{Ca}_2\text{Mg}_4\text{Al}_2\text{Si}_7\text{O}_{24}$. Many analyses of common hornblende show the presence of 60 to 70 per cent of $\text{H}_2\text{NaCa}_2(\text{Mg}, \text{Fe})_4\text{Al}_3\text{Si}_6\text{O}_{24}$, so that this (double) molecule may be considered the dominant component of the chief amphibole. (It should be understood that F is considered equivalent to OH, K to Na, Mn to Fe'' and Fe''' to Al.)

Using the tremolite-actinolite series as one coordinate and the gradation from $\text{H}_2\text{Ca}_2(\text{Mg}, \text{Fe})_5\text{Si}_8\text{O}_{24}$ to $\text{H}_2\text{NaCa}_2(\text{Mg}, \text{Fe})_4\text{Al}_3\text{Si}_6\text{O}_{24}$ as the other coordinate, a diagram can be constructed which shows the chief variations in composition in common hornblende, as illustrated in Fig. 6. It should be clearly understood that this diagram does not show all the variations in composition in common hornblende; in spite of this fact it is possible to show approximately the relation between variations in composition and variations in refringence, as is done by the diagonal lines of the diagram. Unfortunately the writer has not been able to show graphically the relations between other optic properties and the composition. It is possible at present only to make certain general statements regarding these relationships.

1. The optic angle ($2V$) decreases rapidly with increase of the riebeckite molecule, $\text{H}_2\text{Na}_2\text{Fe}_3'''\text{Fe}_2'''\text{Si}_8\text{O}_{24}$; it seems to increase rapidly with increase in the pargasite molecule which is probably $\text{NaCa}_2(\text{Mg}, \text{Fe})_4\text{Al}_3\text{Si}_6\text{O}_{22}\text{F}_2$; according to the data secured by Barnes,¹⁹ the optic angle ($2V$) changes to about 65° no matter what its former value may have been when oxidation changes common hornblende to "basaltic hornblende," whose chief molecule seems to be $\text{NaCa}_2(\text{Mg}, \text{Fe})_3\text{Fe}'''\text{Al}_3\text{Si}_6\text{O}_{24}$.

2. The extinction angle ($Z \wedge c$) increases rapidly with increase in the riebeckite molecule, $\text{H}_2\text{Na}_2\text{Fe}_3\text{Fe}_2\text{Si}_8\text{O}_{24}$; it decreases rapidly to about 0° with increase of the "basaltic hornblende" molecule.

3. The dispersion ($F-C$) increases with increase of the "basaltic hornblende" molecule and probably also with increase of the riebeckite molecule.

4. The refringence increases markedly with increase in the "basaltic hornblende" molecule; it increases much more slowly in most types of common hornblende with increase of the riebeckite molecule; it decreases with increase in the pargasite molecule.

¹⁹ *Am. Mineral.*, **XV**, 1930, p. 393.

5. The birefringence increases considerably with increase in the "basaltic hornblende" molecule; it decreases with increase in the riebeckite molecule.

The diagram (Fig. 6) shows that common hornblende averages about 70 molecular per cent of the aluminous (double) molecule, $\text{H}_2\text{NaCa}_2(\text{Mg,Fe})_4\text{Al}_3\text{Si}_6\text{O}_{24}$, and about 40 molecular per cent of the ferrous iron molecules. It also shows that there is a continuous gradation from the tremolite-actinolite series to the most highly aluminous hornblendes and also a continuous gradation from iron-free magnesian hornblende to magnesium-free ferrous iron hornblende.

In plotting analyses on the diagram (Fig. 6) only two ratios are used. The vertical coordinate gives the ratio between aluminous molecules [dominantly $\text{H}_2\text{NaCa}_2(\text{Mg,Fe})_4\text{Al}_3\text{Si}_6\text{O}_{24}$, but also including $\text{H}_2\text{Ca}_2(\text{Mg,Fe})_4\text{Al}_2\text{Si}_7\text{O}_{24}$] and non-aluminous molecules. The horizontal coordinate expresses the ratio between magnesian molecules and iron molecules, all the iron being included, as well as manganese. The ferric iron, for the purpose of obtaining this ratio, is converted to its equivalent as ferrous iron; this is done because: (1) some analyses are not very accurate in the separation of ferrous and ferric iron, (2) it is now known that the state of oxidation of the iron can be changed in hornblende without destroying the crystal, and (3) it is impractical to try to represent both ferrous and ferric iron molecules separately in a diagram for hornblende.

No attempt has been made to plot all known analyses on the diagram; those have been selected which show that all parts of the diagram correspond with known samples of hornblende (including gradations to the tremolite-actinolite series). Some samples of hornblende include important amounts of molecules not used in the diagram; they are not shown and usually do not fit the diagram well.

The writer regrets that he is not yet able to present diagrams using the correct formulas for alkaline amphiboles nor for basaltic hornblende. He would urge that results given above should be considered as approximations only.

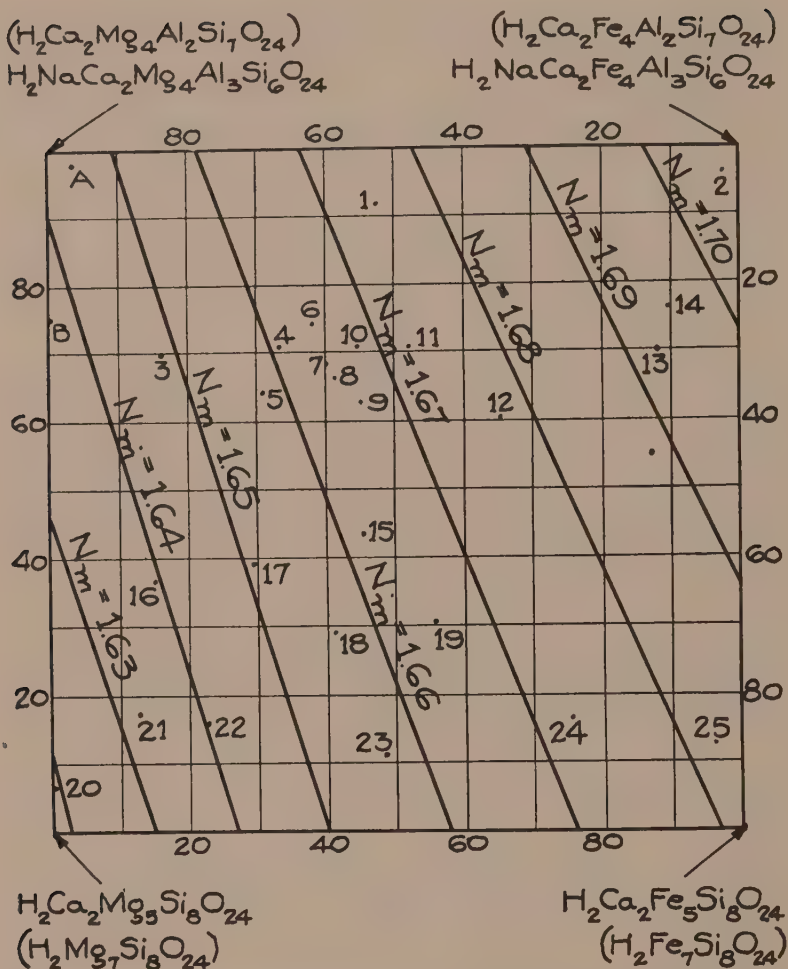


FIG. 6. Variations of composition and refringence in the common hornblende system.

REFERENCES FOR FIG. 6. HORNBLENDE SYSTEM

A. Hornblende, Montville, N. J. Analysis by L. G. Eakins: *U. S. Geol. Surv., Bull.* **64**, 1890, p. 40. No optic data.

B. Hornblende, Ceylon. Analysis by A. K. Coomaraswamy: *Q. Jour. Geol. Soc., LVIII*, 1902, p. 399. No optic data.

1. Hornblende, Monte Somma, Italy. Analysis by F. C. Stanley: *Am. Jour. Sci., CLXXIII*, 1907, p. 41. Optic data by W. E. Ford: *Am. Jour. Sci., CLXXXVII*, 1914, p. 179. $N_m = 1.68$.

2. Amphibole, Babbitt, Minn. S. Richarz: *Am. Mineral.*, **XV**, 1930, p. 65. About 50% $H_2NaCa_2Fe_4Al_3Si_6O_{24}$ and 46% $H_2Ca_2Fe_4Al_2Si_7O_{24}$; the latter lowers

the index (N_m) about .02 as compared with the diagram. Richarz gives: $N_m = 1.690$.

3. "Karinthine," Alps. S. Kreutz: *Sitz. Akad. Wiss. Wien.*, **CXVII**, 1908, p. 875. Analysis by Rammelsberg; optic data by Kreutz. $N_m = 1.643$.

4. Hornblende, Baranaschka Kudnik. W. Kunitz: *N. Jahrb. Min., Bl. Bd.* **LX**, A, 1930, p. 171. $N_o = 1.671$, $N_m = ?$, $N_p = 1.652$.

5. Hornblende, Lanark Co., Ont. V. E. Barnes: *Am. Mineral.*, **XV**, 1930, p. 393. Analysis by R. B. Ellestad; optic data by Barnes. $N_m = 1.6589$.

6. Hornblende, Senftenberg, Austria. A. Marchet: *Tsch. Min. Pet. Mit.*, **XXXVIII**, 1925, p. 494. Analysis by J. Morozewicz; optic data by Marchet. $N_m = 1.663$.

7. Hornblende, Beerberg. W. Kunitz: *op. cit.* $N_o = 1.678$, $N_m = ?$, $N_p = 1.658$.

8. Hornblende, Plauen. W. Kunitz: *op. cit.* $N_o = 1.678$, $N_m = ?$, $N_p = 1.658$.

9. Hornblende, Edenville, N. Y. Analysis by F. C. Stanley: *op. cit.* Optic data by W. E. Ford: *op. cit.* $N_m = 1.6701$.

10. Hornblende, Arendal. W. Kunitz: *op. cit.* $N_o = 1.677$, $N_m = ?$, $N_p = 1.658$.

11. Hornblende, Pulang, N. Celebes. W. Kunitz: *op. cit.* $N_o = 1.681$, $N_m = ?$, $N_p = 1.661$.

12. Hornblende, Renfrew Co., Ont. V. E. Barnes: *op. cit.* Analysis by L. C. Hurd. Optic data by Barnes. $N_m = 1.6980$.

13. Amphibole, Mt. Monadnock, Vt. J. E. Wolff: *Jour. Geol.*, **XXXVII**, 1929, p. 1. $N_m = 1.71$.

14. "Hudsonite," Cornwall, N. Y. Analysis by J. L. Nelson: *Am. Jour. Sci.*, **CLXV**, 1903, p. 227. Optic data by W. E. Ford: *op. cit.* $N_m = 1.71$.

15. Hornblende, Signal Peak, Calif. A. Pabst: *Univ. Calif. Publ. Geol.*, **XVII** 1928, p. 363. N_1 on cleavage = 1.674, N_2 on cleav. = 1.661.

16. Hornblende, Radautal. W. Kunitz: *op. cit.* $N_o = 1.654$, $N_m = ?$, $N_p = 1.633$.

17. Hornblende, San Felix. W. Kunitz: *op. cit.* $N_o = 1.661$, $N_m = ?$, $N_p = 1.641$.

18. Actinolite, New Hampshire. W. Kunitz: *op. cit.* $N_o = 1.659$, $N_m = ?$, $N_p = 1.638$.

19. Actinolite, Piz Valeza. W. Kunitz: *op. cit.* $N_o = 1.663$, $N_m = ?$, $N_p = 1.640$.

20. Tremolite, Ossining, N. Y. Analysis by E. T. Allen and J. K. Clement: *Am. Jour. Sci.*, **CLXXVI**, 1908, p. 101. Optic data by V. E. Barnes: *op. cit.* $N_m = 1.6183$.

21. Actinolite, Greiner, Switzerland. S. Kreutz: *op. cit.* $N_m = 1.6297$.

22. Actinolite, Pierrepont, N. Y. Analysis by F. C. Stanley: *op. cit.* Optic data by W. E. Ford: *op. cit.* $N_m = 1.6382$.

23. Actinolite, Rhode Island. W. Kunitz: *op. cit.* $N_o = 1.663$, $N_m = ?$, $N_p = 1.642$.

24. Actinolite, Nordmark. W. Kunitz: *op. cit.* $N_o = 1.677$, $N_m = ?$, $N_p = 1.658$.

25. Amphibole, Idaho. E. V. Shannon: *Proc. U. S. Nat. Mus.*, **LIX**, 1921, p. 397. $N_o = 1.685$, $N_m = ?$, $N_p = 1.668$.

POSTSCRIPT. The preceding discussion of the amphiboles was presented to the Mineralogical Society of America at Toronto, Ont., on December 30, 1930. Since that time other studies of the amphiboles have been published, notably:

H. Berman and E. S. Larsen: Composition of the Alkali Amphiboles. *Am. Mineral.*, **XVI**, 1931, p. 140.

H. V. Warren: An Occurrence of Grunerite at Pierrefitte, Hautes-Pyrénées, France, *Mineral. Mag.*, **XXII**, 1931, p. 477.

N. Sundius: The Optical Properties of Manganese-poor Grunerites, etc., *Am. Jour. Sci.*, **XXI**, 1931, p. 330.

The article by Berman and Larsen deals with the alkali amphiboles, whereas the writer's discussion is confined almost wholly to the non-alkali amphiboles.

The article of Warren gives the composition and optic properties of a grunerite²⁰ containing 2.23 MnO, 3.12 MgO, 1.51 CaO, 0.70 Na₂O and 0.43 K₂O. The lime and alkalies decrease the birefringence and also the refringence (except for N_p) as compared with the writer's Fig. 3.

The article of Sundius presents an attempt to obtain greater precision regarding the relations between variations in composition and in optical properties. Sundius has succeeded in showing graphically the influence of manganese, of iron and of magnesium on the optic properties of part of the ternary system. He concludes that the pure magnesian end-member would have the optic plane normal to (010). This conclusion is based solely upon the idea that the indices of refraction (especially N_m and N_p) vary along straight lines; such a rectilinear variation for N_p is not demonstrated by the data and seems improbable to the writer.

²⁰ Warren states that the name of the iron amphibole is properly grunerite, not grünerite.

AN ARIZONA GOLD NUGGET OF UNUSUAL SIZE¹

ROBERT E. S. HEINEMAN, *University of Arizona.*

Recently a gold nugget of a size sufficient to be worthy of description was brought into the office of the Arizona Bureau of Mines.

The owner of the nugget, Mr. John B. Ehrhart, stated that it was found about the middle of November, 1930, in a placer in the Weaver district, Arizona. The exact location, according to Mr. Ehrhart, was about a mile from Octave, on the property controlled by the Red Bank Gold Placer Company. The Weaver district and the Octave postoffice are in southern Yavapai County about seven or eight miles east of Congress Junction.

The district has been described by Wilson² who says, "The Weaver Mountains, which are made up mainly of pre-Cambrian granites and schists, overlain by Tertiary lavas, contain numerous gold-bearing quartz veins that were the source of these placers.

"Broadly speaking, the placer ground covers an area of approximately 8 by 5 miles. It is said that the most productive portions, which were in the northern half of this area, included about 10 acres on the north-eastward-sloping top of Rich Hill; certain portions of the sides of the hill; the channels and benches of Weaver, Antelope, and other washes; and the gravel mesas that lie between these washes. On the top of Rich Hill the gold occurs on bedrock that in places is covered with boulders and a thin layer of residual clay. Along the washes below, and in the mesas, however, the placer material consists of iron-stained gravel and sand, up to 10 or more feet thick, together with abundant, subangular boulders that are 2 to 6 feet in diameter."

The Rich Hill channel is noted for its heavy gold. Blake says³ that nuggets were found which were worth approximately \$450, \$400, \$300, and \$150. Three other lumps were worth \$1008 in the aggregate. Hardly any fine gold was found. The nugget described in this paper, while not the largest discovered, belongs in the group of those of major proportions.

The story of the discovery of these placers is rather interesting.

¹ Published by permission of the Director, Arizona Bureau of Mines.

² Wilson, E. D., Arizona gold placers, *Univ. Ariz., Ariz. Bur. Mines, Bull.* 124, 26-28, 1927.

³ Blake, W. P., *Rep't of the Territorial Geologist, in Rep't of the Governor of Arizona*, 66, 1899.

Again quoting Wilson,⁴ "In the early sixties, certain Indians who came to La Paz, near the Colorado River, to trade, reported the occurrence of much gold many miles farther east. One of them was persuaded to guide a party, consisting of Capt. Pauline Weaver, Maj. A. H. Peeples, and others, to the locality. This party happened to camp at the base of Rich Hill, after their guide had deserted them on the desert north of Wickenburg. A Mexican of the party, while looking for their strayed animals, discovered loose nuggets on the top of Rich Hill. This discovery led . . . to the finding of the placers on Weaver and Antelope creeks.

"This whole area became the scene of intense activity, and in 5 years, according to Hall,⁵ produced about \$500,000 . . . and the production of the whole area, prior to 1883, was estimated by Hamilton⁶ at \$1,000,000 Production from 1905 to 1924, inclusive, amounted to about \$75,500"

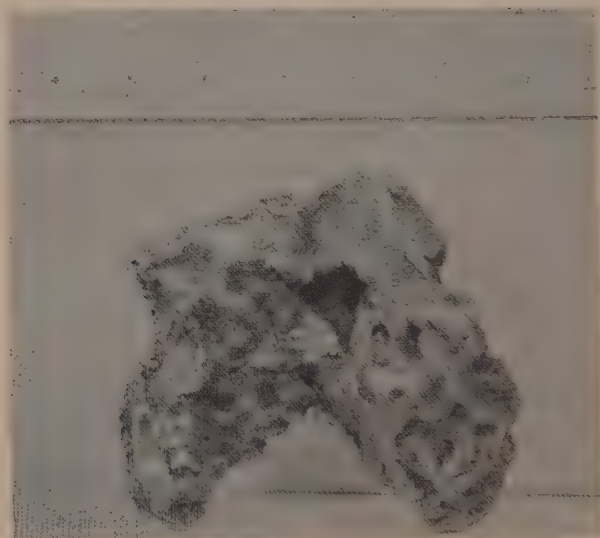


FIG. 1. Gold nugget from the Weaver placers, Arizona. Natural size.

Mr. Ehrhart's nugget is in general outline shaped somewhat like a human molar. (Fig. 1). It measures approximately 53 mm. across the widest portion of the "roots," and 47 mm. from the bottom of

⁴ Wilson, E. D., *op. cit.*

⁵ Hall, Sharlot, former State Historian, personal communication.

⁶ Hamilton, Patrick, *Resources of Arizona*, 1883.

the "root" to the "crown." Several fragments of slightly iron-stained quartz remain in the center of the mass. The surface is well worn on the exposed portions but where protected is rather rough. The total weight is 270.90 grams. The weight in water was found to be 250.32 grams. Heikes states⁷ that all of the gold from the Weaver placers has a fineness of 910. Assuming that the gold in this nugget also has a fineness of 910 several calculations were made. The nugget was not available for assay purposes.

The specific gravity of gold of 910 fineness is 18.53. Using this figure it may be calculated that the nugget consisted of 252.38 grams of metal and 18.52 grams of quartz. 252.38 grams of gold of a fineness of 910 is equivalent to 229.67 grams of pure gold which is worth \$152.62 and 22.71 grams of silver which is worth about 21 cents at the date of writing. (Note: Since this article was written, the nugget has been procured by Dean G. M. Butler of the University of Arizona.)

⁷ Heikes, V. C., *U. S. Geol. Survey, Min. Res.*, I, 259, 1912.

NOTES AND NEWS

MAGHEMITE OR OXYMAGNETITE?

A. N. WINCHELL, *University of Wisconsin.*

The existence of highly magnetic ferric oxide has been known for more than eighty years, but its relation to other iron oxides is still not fully determined. It was noticed by Plücker¹ in 1848 and by Robbins² in 1859; it has been discussed repeatedly; recent studies include those of Welo and Baudisch,³ Sosman and Posnjak,⁴ Gruner,⁵ Twenhofel,⁶ Osborne⁷ and others. Sosman and Hostetter⁸ present evidence tending to show a (nearly?) complete series of "solid solutions" from hematite to magnetite. It seems probable that this series of "solid solutions" is to be explained as various stages in the gradual process of oxidation of magnetite, although the reverse process—that is, the gradual reduction of hematite—may be important also.

Most of the studies of these oxides of iron, upon both natural and artificial products, lead only to indefinite conclusions because they were not accompanied by X-ray studies, and therefore it is difficult or impossible to determine whether the samples examined consisted of pure magnetite or pure hematite or one of these two with submicroscopic inclusions of the other. On the other hand both Gruner and Twenhofel prove conclusively that pure artificial magnetite may be oxidized to the composition of hematite without losing the magnetite space-lattice and with no admixture of the hematite space-lattice. Wagner⁹ states that "oxidized magnetite" or "ferromagnetic ferric oxide" is abundant in the upper part of the norite zone of the Bushveld igneous complex; he made no X-ray study of the material, but had the benefit of a microscopic examination of it by Schneiderhöhn. Since the substance is found in nature it should have a simple mineral name; he considers "ferromagnetic ferric oxide" too long and says that "oxydized magnetite" is "misleading, as it [the substance] contains no ferrous oxide"; therefore he suggests that it should be called "maghemite."

The writer agrees fully with Wagner that "ferromagnetic ferric oxide" is unsatisfactory as a mineral name, but he considers "oxydized magnetite" as strictly accurate, since it does not imply the necessary presence of ferrous oxide nor require the entire absence of ferrous oxide; the artificial (and probably the natural) substance may contain some ferrous oxide, but in the case of complete oxidation (rather easily accomplished) contains none. However, "oxydized magnetite" is too long to be satisfactory as a mineral name and the writer would suggest that it might be abbreviated to *oxymagnetite*.

Wagner's name seems undesirable since it suggests that the substance is intermediate between magnetite and hematite or else is hematite which has become

¹ *Pogg. Ann.*, **LXXIV**, 1848, p. 321.

² *Chem. News*, **I**, 1859, p. 11.

³ *Phil. Mag.*, **L**, 1925, p. 399.

⁴ *Jour. Wash. Acad. Sci.*, **XV**, 1925, p. 329.

⁵ *Econ. Geol.*, **XXI**, 1926, p. 375.

⁶ *Econ. Geol.*, **XXII**, 1927, p. 180.

⁷ *Econ. Geol.*, **XXIII**, 1928, pp. 724-761, 895-922.

⁸ *Jour. Amer. Chem. Soc.*, **XXXVIII**, 1916, p. 807

⁹ *Econ. Geol.*, **XXII**, 1927, p. 845.

magnetic. If hematite can be deoxidized to the composition of magnetite while retaining its own space-lattice (as seems probable) and, if this process causes it to become highly magnetic, then material of that kind might well be called maghemite. Of course, such a substance might resemble oxidized magnetite in its appearance, but it would necessarily be different in external form, in the symmetry of its internal structure and in its optical properties.

Walker¹⁰ has recently suggested that the name maghemite should be applied to an iron-rich member of the series which he writes as follows:

Titanic sesquioxide
Ilmenite
Maghemite
Ferromagnetic ferric oxide

It is unfortunate that, as yet, there is no evidence of an X-ray examination to determine the chief space-lattice of the material studied by Walker. Chemical analysis and microscopic study seem to indicate that it is actually a titaniferous maghemite as that term is understood by the writer. It seems probable, therefore, that the answer to the question: "Maghemite or oxymagnite?" is: "Both."

BOOK REVIEWS

UNIVERSAL DREHTISCHMETHODEN, M. REINHARD. 119 pages, 49 figures.
B. Wepf and Cie, *Basel*, 1931. Price \$2.40 bound.

The purpose of this book is to present an outline of the theory of crystal optics for the beginning student and to apply these principles to the study of universal stage methods. The stage used is the Leitz model and the nomenclature is European. The recommended procedure is also European, consisting of orienting an unknown, and plotting all known critical data on a stereographic projection. For accuracy Professor Reinhard recommends the use of standard accessories commonly employed in careful work of this sort.

There is evident throughout the text the necessity at times of minute detail and a willingness to carry out lengthy graphical constructions to obtain the desired goal. Although in America the possibilities of the Universal stage is generally admitted its comparative lack of use seems to be attributable to an unwillingness to execute these details of graphical constructions. Professor Reinhard's book is a splendid exposition of the advantages to be gained by careful and detailed work of the sort described.

The last half of the book is devoted to a discussion of the universal stage method, as applied to plagioclase determinations. The methods consist of making stereographic projections of the optical elements of the unknown plagioclase with relation to a known crystallographic direction and comparing this projection with plates provided in the book. On the plates there are curves—"Migrationskurven"—showing the possible positions of optical symmetry elements according to the composition of the plagioclase. There should be a reasonable agreement between the projection of the unknown and related points on the curves of the plate. The points of the unknown indicate by their positions on the "Migrationskurven" the composition of the plagioclase. The curves have already been published in similar form in the earlier book by L. Duparc and M. Reinhard—"La détermination des plagioclases dans les coupes minces." They are also reproduced in A. N. Winchell's Part II, Optical Mineralogy.

¹⁰ *Univ. Toronto Stud. Geol. Ser.* No. 29, 1930, p. 17.

Twenty-five pages are devoted to an excellent, lucid description of plagioclase twinning, which is used to correlate optical elements with crystallographic directions. Details for the recognition of the various types of twins are fully described.

Those who still do a large part of their determinative work with thin sections will find Professor Reinhard's book a very helpful guide indeed if they are not already acquainted with universal stage methods. Those who are making use of immersion methods will find less that is suitable for application to their immediate problems.

R. C. EMMONS

ANLEITUNG ZUM BESTIMMEN DER MINERALIEN, FUCHS-BRAUNS.
Eighth Edition, 223 pages, with 27 illustrations in the text. Alfred Toepelmann, Giessen, 1921.

The seventh edition of the very serviceable tables for the determination of minerals, revised by Professor Reinhard Brauns of the University of Bonn, was reviewed in some detail in February, 1922. (Vol. 7, p. 30). No important changes have been made in the new edition.

E. H. KRAUS

PROCEEDINGS OF SOCIETIES

NEW YORK MINERALOGICAL CLUB

The regular meeting of the New York Mineralogical Club was held at the American Museum of Natural History, on the evening of March 18, 1931, with the president, Mr. Allen, in the chair. Mr. Harry W. Hicks of Jersey City, N. J., was elected to membership. The names of the following candidates were read and referred to the membership committee for report at the following meeting: Mr. H. Alban Anderson, Mr. W. R. Schenck, Mr. John H. Fisher, Mr. Raymond H. Torrey, Miss Lillian Fraser and Miss Jane Kessler.

The nominating committee reported the following recommendations for the officers of the ensuing year: President, Mr. Frederick I. Allen; First Vice President, Mr. George E. Ashby; Second Vice President, Dr. Horace R. Blank; Secretary, Mr. Daniel T. O'Connell; Treasurer, Mr. Gilman S. Stanton. In accordance with the Constitution, the report was received, and the recommendations laid over until the following meeting, when other nominations may be made, and the election will be held.

By special arrangement, this meeting was held jointly with the New York Microscopical Society, whose president, Mr. Needham, was then invited to the chair, and presided during the remainder of the meeting.

The speaker of the evening was Dr. L. C. Wills of Philadelphia, who discussed *Microscopical Mineral Mounts and Their Preparation*. He explained the advantages for an intensive study of mineral characters and crystal forms to be had from the microscopical specimens. He showed the fascination of microscopical study, and discussed in detail the preferred methods of mounting and utilizing specimens. Many questions were asked by those present, and effectively answered by the speaker.

A rising vote of thanks was extended to Dr. Wills; and the meeting then adjourned to enjoy the examination of a number of microscopical mineral specimens brought by him, several binocular microscopes having been loaned for the occasion.

JAMES F. MORTON, *Secretary*